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IS 11182-1 (1984): Guide for evaluation of insulation systems of electrical equipment, Part 1: Identification, evaluation and ageing mechanisms [ETD 2: Solid Electrical Insulating Materials and Insulation Systems]



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Indian Standard

GUIDE FOR THE EVALUATION OF INSULATION
SYSTEMS OF ELECTRICAL EQUIPMENT

PART 1 IDENTIFICATION, EVALUATION
AND AGEING MECHANISMS

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Indian Standard

GUIDE FOR THE EVALUATION OF INSULATION SYSTEMS OF ELECTRICAL EQUIPMENT

PART 1 IDENTIFICATION, EVALUATION AND AGEING MECHANISMS

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Indian Standard

GUIDE FOR THE EVALUATION OF INSULATION SYSTEMS OF ELECTRICAL EQUIPMENT

PART 1 IDENTIFICATION, EVALUATION AND AGEING MECHANISMS

0. FOREWORD

0.1 This Indian Standard (Part 1) was adopted by the Indian Standards Institution on 28 November 1984, after the draft finalized by the Electrical Insulation Systems Sectional Committee had been approved by the Electro-technical Division Council.

0.2 This standard consists of several parts. This Part 1 is intended to cover all general aspects relating to evaluation of insulation systems, such as identification, general principles on which functional evaluation procedures are based and guidelines on understanding ageing mechanisms and methods of diagnostic testing. Subsequent Parts are intended to deal with guidelines on test procedures to evaluate behaviour of insulation systems under different factors of influence.

0.3 This standard (Part 1) is editorially organized in different sections as follows:

- a) Section 1 contains the scope of the series together with definition of terms,
- b) Section 2 contains directions and considerations pertaining to the establishment of the codes for insulation systems in particular equipment,
- c) Section 3 deals with functional tests for the assessment of the capabilities of insulation systems and procedures for evaluating test results or service experience in terms of insulation systems codes, and
- d) Section 4 describes mechanism of ageing of insulation systems and methods of diagnosis.

0.4 This standard (Part 1) also includes hypothetical examples of specifications for evaluating and identifying particular systems (*see 7.8*). These cover a case of insulation of a mass produced product and a case of insulation of

a more individually designed equipment. However, these examples are purposely not realistic as they are meant to supplement and explain all guidelines in the standard.

0.5 When the performance of an insulation system is evaluated by accelerated functional tests, and if the ageing mechanisms under the conditions of test differ from those in actual service, results obtained may be misleading. Therefore the equivalence of the ageing mechanism in the test and in service shall be verified before prescribing the test. The importance of such verification procedures increases with the degree of stress intensification. Verification procedures are given in 8.

0.6 Test methods which are especially sensitive in finding out changes in test specimen's condition, may have the advantage that the tests at relatively less intensified stress can be specified to determine the trend of the system's characteristics of ageing rate.

0.7 The functional test procedures may require the selection of an arbitrary end-point criterion which does not correspond to actual apparatus failure. This aspect is under consideration.

0.8 In the preparation of this standard (Part 1) considerable assistance has been derived from the following publications issued by the International Electrotechnical Commission:

IEC Pub 505 (1975) Guide for the evaluation and identification of insulation systems of electrical equipment.

IEC Pub 610 (1978) Principal aspects of functional evaluation of electrical insulation ageing mechanisms and diagnostic procedures.

SECTION 1 GENERAL

1. SCOPE

1.1 This standard (Part 1) is a guide for Technical Committees engaged in developing specifications for evaluation and identification of insulation systems in particular equipment. It is not the purpose of this guide to establish codification standards for the operational life of electrical equipment but rather to supply a framework within which standards for insulation systems can ultimately be established by the appropriate Equipment Technical Committee.

NOTE — This guide relates to insulation system aspects only. Insulation is not the only determinant of equipment life.

1.2 This standard (Part 1) covers guidance on identification and evaluation of insulation systems and describes mechanism of ageing of insulation

systems and methods of ascertaining correlation of ageing in tests and in actual service.

2. OBJECT

2.1 The object of this guide is to:

- a) define the terms used,
- b) recommend a coding procedure for expressing compliance of insulation systems with specified service requirements,
- c) recommend preferred insulation system codes to minimize the number of functional tests,
- d) state general principles for the functional evaluation of insulation systems,
- e) recommend typical contents of functional test procedures of insulation systems, and
- f) state the principal aspects of ageing mechanism and diagnostic techniques.

3. TERMINOLOGY

3.0 For the purpose of this standard, the following definitions shall apply.

3.1 General Terms

3.1.1 *Insulation System* — An insulating material, or as assembly of insulating materials, to be considered in relation with associated conducting parts, as applied to particular type or size or part of electrical equipment.

NOTE — A single piece of electrical equipment may contain several different insulation systems.

3.1.2 *Intended Performance* — Representative life of an insulation system under service conditions as specified in the code. This does not constitute a commercial guarantee.

3.1.3 *Estimated Performance* — Life of the insulation system in service estimated in accordance with the appropriate evaluation procedures established by the responsible Technical Committee, on the basis of service experience and/or the results of functional tests.

NOTE — Intended performance and estimated performance should be expressed in the same dimensions (for example, time and number of operations).

3.2 Terms Relating to Coding Insulation Systems

3.2.1 Insulation System Code — A sequence of symbols or abbreviations representing specified service requirements for an insulation system in a particular type of electrical equipment and stating demonstrated compliance.

3.2.2 Preferred Insulation System Codes — A small number of insulation system codes selected from all those possible for a given type of equipment in order to restrict the number of specified test procedures.

3.3 Terms Relating to Service, Stresses and Ageing

3.3.1 Service Conditions — Conditions in terms of factors of influence and duty to which electrical equipment is exposed during actual operation or when connected but not operating.

3.3.2 Service Requirements — Requirements expressed in terms of factors of influence, intended performance and duty corresponding to service conditions with which electrical equipment has to comply.

3.3.3 Serviceability — The ability to function as intended at any particular time.

3.3.4 Mode of Operation — Characteristic related to the frequency of operation, the duty and the rate of occurrence of external disturbances of different kinds.

3.3.5 Factor of Influence — Stress or environmental influence acting on insulation in equipment during service.

3.3.6 Ageing — Irreversible deleterious changes to the serviceability of insulation systems. Such changes are characterized by a failure rate which increases with time.

3.3.7 Ageing Factor — Factor of influence producing ageing.

3.4 Terms Relating to Testing

3.4.1 Functional Test — A test in which the insulation system of an equipment or part thereof or a test model is exposed to ageing factors simulating service conditions, in order to obtain information about serviceability.

3.4.2 Test Model — A model representative of equipment or part thereof intended for use in a functional test.

3.4.3 Forced Ageing — The acceleration of ageing by intensifying the level and/or the frequency of application of the ageing factors beyond normal service conditions.

3.4.4 Accelerated Test — Functional test applying forced ageing in order to reduce the testing time in comparison with intended performance.

3.4.5 Diagnostic Factor — A stress applied to the insulation of a test specimen in order to establish its state without significantly adding to the ageing.

3.4.6 End-Point Criterion — A selected value of characteristic of a test specimen indicating its vanishing serviceability or arbitrarily chosen for the purpose of the comparison of insulation systems.

3.4.7 Proof Test — Application of a fixed level of a diagnostic factor to a test specimen to establish whether the end-point criterion has been reached.

SECTION 2 INSULATION SYSTEM CODING PROCEDURE

4. CODING INSULATION SYSTEMS

4.1 The use of an insulation system code is a declaration of the capability of an insulation system so identified in function under conditions and with an intended performance as specified in the code.

4.2 It is a basic principle that the compliance of an insulation system with the service requirements specified by its code shall be demonstrated either by evaluation of service experience, or by functional tests as specified in relevant specification.

4.3 A coding procedure is proposed for the development of codes for insulation systems of particular types of electrical equipment. An insulation system code is an instrument of communication between the user and the manufacturer of electrical equipment.

4.4 The code consists of a sequence of digits each representing one item needed for identifying the service requirements of the insulation systems (see 5.1).

4.5 The development of individual codes requires the definition of the service requirements relevant to the insulation, and the specification of their levels, ranges or variants. Coding of insulation systems requires the specification of the compliance criteria.

4.6 The coding procedure enables, with widely differing degrees of sophistication, the development of codes for insulation systems in particular types of equipment. In order to meet the requirements of those equipments which need very few elements to characterize their insulations the procedure has been developed in such a way that the codes for different equipment may be of different complexity.

4.7 The time aspect of insulation behaviour, that is the matter of a reasonable lifetime, number of switchings or some other life criterion, is an important aspect and has been covered in IS : 1271-1958*.

4.8 In this guide, the time aspect is made explicit through the concept 'performance'. As a service requirement, 'intended performance' will be an element of all insulation system codes. The test results (or service experience) have to be expressed by a quantity of the same dimension as intended performance, which is called 'estimated performance'.

4.8.1 An intended performance figure is a statement of typical insulation behaviour without any implication concerning a possible commercial life guarantee.

NOTE — There is a trend to supplement the time aspect of the compliance criteria with reliability statements. The introduction of reliability into the codes would be considered in the future depending on the progress and the general acceptance of suitable methods.

4.9 The number of possible insulation system codes for specific equipment will normally be large, being the product of the number of symbols used for each of the elements. Raising some very few of the possible codes to the rank of preferred insulation system codes and relating the main test procedures to these codes will allow the number of test procedures to be kept at a reasonable level.

5. INSULATION SYSTEM CODES — GENERAL DESCRIPTION

5.1 General Description—The insulation system code consists of a sequence of digits (or X) preceded by the identification of the document in which all elements of the code are defined, and the declaration 'INS' (insulation system).

The position of a digit in the sequence unambiguously defines the kind of code element, and the value of the digit specifies the level, range or variant of the element.

*Classification of insulating materials for electrical machinery and apparatus in relation to their thermal stability in service.

The order of the code elements is as follows:

T E A M — P D

The letters stand for :

<i>T</i> (first digit)	=	thermal factor of influence
<i>E</i> (second digit)	=	electrical factor of influence
<i>A</i> (third digit)	=	ambient (environmental) factor of influence
<i>M</i> (fourth digit)	=	mechanical factor of influence
<i>P</i> (fifth digit)	=	performance — intended
<i>D</i> (sixth digit)	=	duty — mode of operation

The group *T E A M* combines factors of influence, The group *P D* represents intended performance and duty as differentiated from these factors and is therefore kept separate by a hyphen.

Unused elements to the right of the last used element should be deleted from the code in both groups. The group *T E A M* can be reduced successively from the full form to the first element *T*. The unused elements to the left of the last one which is used must be represented by zeros. The group *P D* may be reduced to *P*.

The shortest possible code is *T — P*. A code with, the example, *E*, *A P* and *D* will have the form: *O E A — P D*. More complete examples are given in Appendix A.

Equipment Technical Committees have to decide which factors of influences are sufficiently relevant to be included in their codes.

The development through periodic revisions of a particular code from simpler to more advanced uses is possible within wide limits. If desired, the existing thermal classifications may be converted to the formulation of the new coding procedure.

5.2 Introducing Additional Code Elements — Additional factors of influence may, if required, be introduced into the code to follow the fourth digit of the factor group *T E A M*. For example, introducing a factor of influence 'radiation' (*R*) would yield the code *T E A M R — P D*.

In the same way, requirements such as the fail-safe aspect may be introduced to follow the group *P D*. For example, introducing the element 'flammability' (*F*) would yield the code *T E A M — P D F*.

When a code element is to include two or more variants of a factor of influence, for example, pressure, bending shock and vibration for M , these shall be given in brackets in the position of the single digit. A code with two mechanical elements would thus have the form $TEA (M_1 M_2) - PD$ (see Note 1 of Appendix C).

5.3 Identification of Insulation System Codes — This identification is to be an unequivocal reference to the specification in 5.1.

The code begins with the identification of the specification in which the definitions of the digits used in the codes for the particular equipment are provided. If this specification contains a subdivision of equipment into types or parts, and separate codes are assigned to them the identification should be supplemented by an additional reference preceded by a colon (:). For example, the identification could be:

IS :

5.4 Alternative Format (Tabulated) — If it is required to present codes in a form which explicitly indicates the meaning of the different code elements, the following format is recommended:

Identification	$TEAM - PD$
(for example IS :) INS	(Code digits)

This alternative format might be suitable for use, for example, in commercial documentation.

5.5 Specifying the Code Digits — Generally the digit values 1 to 9 should be used to represent statements regarding levels, ranges or variants of the code elements. If an element is considered significant, but no precise value can be assigned, the symbol \times should be used. The digit 0 should be used for the statement 'not present or not considered to be significant'. When any code element exceeds digit 9, all the code elements will be separated by semicolons [for example (Identification) INS 4; 12; 3; 3-4; 1].

In many cases, the use of a few digits or of a single digit will be adequate. Unauthorized use of digits not defined in the reference specification should be avoided by the explicit blocking statement 'NA' (non-applicable).

The meanings attributed to digits may be of different types. They may range from simple qualitative statements ('normal' 'acceptable life in equipment'), qualitative specifications of the variant of a factor of influence ('bending', 'tension', 'vibration') to semi-quantitative ('heavy starts 5 to 20

per week'), quantitative ($130^{\circ}\text{C} < T \leq 155^{\circ}\text{C}$) and quantitative with qualifications ('Passed Tests given in clause xyz of IS ...').

The level of a factor of influence may be externally defined (for example atmosphere, radiation), or it may be determined by the operating conditions and the design in combination (for example mechanical stresses, maximum insulation temperature). This may be taken into account in the formulation of qualifying statements, for example: 'As designed, at rated load'.

5.6 Multiple Tabulated Format — For some code elements, a higher digit will represent more severe requirements (for example, temperature). This will not normally be the case for other elements (for example, environments). One insulation system in a certain equipment may, after the required functional testing, be given two or several codes with different digit values for such factors of influence. For example, if the system complies with the constant statements $T = 5$, $E = 5$, $P = 1$, but with the two A -statements, namely, $A = 4$ (industrial polluted atmosphere) and $A = 6$ (tropical environment), this hypothetical insulation system would merit the codes INS : 554-1 and INS:556-1.

In such cases the alternative format of 5.4 may be used in a multiple box. For example, in the case given above, this table could be as follows:

Identification	T	E	A	P
(.....) INS	5	5	4	1
(.....) INS	5	5	6	1

5.7 Code Elements

5.7.1 Thermal Factor of Influence (T) — This factor of influence will usually represent insulation temperature (mean or maximum). Technical Equipment Committees are free to choose temperatures at their own discretion. However, if there are no compelling technical reasons to do otherwise, it is recommended that temperatures shall be specified with 25°C intervals, that 130°C be one of the values, and that this value be represented by the digit 4.

5.7.2 Electrical Factor of Influence (*E*) — Usually *E* will be specified in terms of voltage and/or stress and/or overvoltages (transients). When specifying *E*, Technical Committees will recognize that electrical stress is normally a design parameter. If both normal service voltages and over-voltages are to be specified, an additional code element (see 6.2) might be introduced.

5.7.3 Environmental Factor of Influence (*A*) — Whenever possible, standard environments specified in relevant Indian Standard should be referred to in particular equipment. However, since the total number of environments is very large, it is not recommended that they be represented by common statements applied uniformly in all codes for different equipments. The introduction of additional elements may be required (see 6.2).

5.7.4 Mechanical Factor of Influence (*M*) — The mechanical stresses acting on insulation in service and their effects on insulation life are, in many cases, difficult to specify quantitatively. Often, qualitative statements may be adequate. In other cases, quantitative specifications need to be developed.

It might be desirable, in some cases, to define the mechanical stress in terms of its cause (for example, current per slot in rated service or under short-circuit conditions). Factor *M* may, in certain cases, require the introduction of additional elements (see 6.2).

5.7.5 Performance — Intended (*P*) — The behaviour of an insulation system under given operating conditions is expressed by its estimated performance, which is determined from functional tests or available service experience.

The *P*-level will be related to the estimated performance according to specified procedure.

5.7.6 Duty — Mode of Operation (*D*) — The characteristic can be related to the frequency of operation, the duty type and the rate of occurrence of external disturbances of different kinds.

5.8 Preferred Insulation System Codes — Insulation system codes represent service requirements for the insulation of particular equipment. The number of possible codes therefore will normally be substantial. If the corresponding number of tests were to be performed, the required amount of testing would become unacceptable in most cases.

5.8.1 Some very few codes of the whole code list may therefore be selected to form what will be termed 'preferred codes'. A preferred code will normally represent a set of service requirements chosen as being typical, although it may also be chosen to represent extreme requirements.

Each preferred code will normally cover a number of those which are not preferred. When the preferred codes have been established, all the

ordinary codes covered by each of them should be listed. The Equipment Technical Committee should decide which codes are to be included and define testing procedures for the preferred codes.

A single test corresponding to a preferred code for the requirements represented by several codes should be used wherever possible. This means that when the service requirements for the insulation of a certain equipment are stated by a code, the insulation system shown to comply with the next higher preferred code will usually be chosen.

Example:

Consider hypothetical insulation systems which must withstand the following ambient conditions having the associated digit values for A:

Humidity.....1

Sulphur dioxide..... 3

Sand.....5

Humidity + sulphur dioxide..... 7

If we consider the code digits for *T*, *E* and *P* to be constant, 3, 1 and 1 respectively, there are four possible codes namely,

(Identification) INS : 311-1

(Identification) INS : 313-1

(Identification) INS : 315-1

(Identification) INS : 317-1

The responsible Equipment Technical Committee may choose the last code [that is (Identification) INS : 317-1] as 'preferred code'.

An insulation system qualified for the code with the digit sequence 317-1 will, according to the rules established by this Equipment Sectional Committee, also qualify for 311-1 and 313-1, but not for 315-1, because sand is not included in the factors of influence relevant to the code digits sequence 317-1.

NOTE — General rules, providing a basis for the selection of preferred codes, will be prepared by concerned Technical Committee.

5.9 Coding Based on Service Experience — see 7.7.

5.10 Presentation of Insulation System Codes in Equipment Standards —

Examples of hypothetical code specifications for two kind of equipment are given in Appendix A.

5.11 A flow chart for coding procedure for insulation system is given in Appendix B.

SECTION 3 PROCEDURES FOR FUNCTIONAL EVALUATION

6. FUNCTIONAL EVALUATION

6.1 General Principles — Guidelines for functional evaluation are based on the principle that compliance of an insulation system with a code of service requirements shall be demonstrated either by evaluation of service experience or by functional tests on full-scale equipment (or parts thereof, or on models).

Service experience, when available, is a basis for evaluating insulation systems provided the variation during operation of the service conditions permits.

Functional tests may be performed on full-scale equipment reproducing the action of the ageing factors existing in service. The ageing factors should, where possible, act simultaneously if they do so in service. Intensification of one or more of the factors of influence permits, comparative results to be obtained in a shorter time.

Instead of full-scale equipment, models may be tested in the same way.

Any test procedure developed in accordance with the above should be proved to give statistically acceptable reproducibility before being introduced into an Indian Standard Specification.

6.2 Functional Tests — For long life applications, an evaluation of a new insulation system by means of functional tests requires comparison with a service-proven insulation system subjected to corresponding experimental conditions.

For short life applications, the insulation of the actual equipment may be evaluated without comparison with a known insulation system.

The evaluation of the capabilities of insulation systems for radically new conditions (or, possibly, for radically new insulation systems for known conditions) is necessary even though generally accepted methods are not available.

Such evaluations have, consequently, to be approached in a tentative and cautious way, and codification will not be possible until pertinent rules have been established by the appropriate Technical Committee.

The use of preferred codes will reduce testing costs, and simple tests may be possible for slight modifications of systems and requirements.

6.3 Deriving the Estimated Performance — The behaviour of an insulation system under the conditions of a test shall be expressed by means of an estimated performance value. Rules for translating the test results into estimated performance shall be given in a test specification to enable assignment of a code.

Procedure shall be specified for deriving estimated performance from available service experience.

7. PROCEDURE FOR FUNCTIONAL EVALUATION

7.1 General — Procedures for the functional evaluation of insulation systems should be constructed to provide acceptable confidence at reasonable costs.

Care shall be taken that the test specification does not restrict the freedom of the equipment designer to select the best compromise, using his experience and knowledge.

Insulation systems for equipment with a typical service life considerably exceeding a reasonable testing time will normally require accelerated testing, with an evaluation procedure based on extrapolation, on equipment or parts thereof or models. In the present state of the art, such tests are based on comparison with a known (reference) insulation system which is service-proven in similar equipment. The reference system should qualify for the envisaged or a moderately different code. More than one test level will usually be required, depending on the evaluation case (*see 7.5.1 and 7.5.2*).

For short-life equipment, tests may be made on equipment or models without acceleration or extrapolation of the test results, possibly by shortening or neglecting rest periods in case where they do not affect the serviceability.

In such cases, one test level corresponding to the specified service conditions may be sufficient.

7.2 Test Specimens — Wherever practicable, the equipment itself should be used for the determination of the estimated performance of the insulation system. Insulation systems may be evaluated by models rather than by full-size equipment when required because of size and convenience. Models should be made to embody the essential elements of the equipment they simulate, taking care to provide that ageing processes similar to those in service can be imposed.

In many cases the behaviour of the insulation system depends significantly on the design of the essential elements (for example, design of the cooling ducts in the slot of the stator of air-cooled generators). All relevant characteristic details of the design should be represented in the model.

It is desirable to specify only one test model for a certain insulation system. This could be the case when all the factors of influence can be applied to the same model, preferably simultaneously. If this is not possible or practical, it would be advantageous to specify several (two or three) simpler models for use in supplementary tests, in addition to or even instead of the more complicated model for the main test (*see 7.3.1*).

If necessary, screening tests should be included to assure uniformity of the models being tested. When size reduction of the model is applied, the following should be considered:

- a) The same manufacturing process should be used for the specimens as for the equipment in production (for example, the polymerization of resins shall be the same);
- b) When a thermal stress is applied, to have, if relevant, the same thermal gradient in the model and in the equipment, in order to achieve the same differential expansion. In this case, it might also be necessary to test full-size specimens;
- c) If electric stress is relevant, then the model should be designed to give local electrical fields of the same magnitude as in the equipment;
- d) If diffusion of gases in insulation is relevant, the free surface area and volume of the model insulation should be dimensioned so that the diffusion time constant is approximately the same as in full-size equipment; and
- e) When mechanical stress is applied, to avoid unwanted mechanical resonance phenomena.

The number of test specimens for a particular functional test depends on the features of the test programme (*see 7.4.1, 7.5.1 and 7.5.2*).

7.3 Functional Tests : Ageing Procedure

7.3.1 General — A characteristic of functional testing is the application of all relevant factors of influence to the test object. Ideally, stresses that act at the same time in service should be applied simultaneously.

It is recognized that the rigorous application of this general rule may not always be possible because world-wide know-how is not available to permit the interpretation of results of functional tests involving the simultaneous application of several ageing stresses. Moreover, simultaneous application of stresses would, in many cases, make functional tests unacceptably complicated and expensive.

Therefore simplified procedures may have to be adopted, even though it is known that simultaneously acting stresses may cause interactions which change the ageing mechanisms. The absence of such interactions during tests with only single stress applied forbids the results of such tests being superposed to indicate the results of simultaneous application of these stresses.

In electrical equipment, either one factor of influence will dominate the ageing process, or more than one ageing factor is important. Consequently the following different ageing methods are possible:

- a) *One dominant ageing factor*—The dominant factor of influence is applied during the ageing process. Other factors may be at normal levels during ageing and be used as diagnostic factors of determining an end-point.
- b) *More than one important ageing factor*—In this case, three possible methods of evaluation may be used:
 - 1) All ageing factors are applied simultaneously. In this case interactions may occur. Diagnostic factors may be used to determine an end-point, although this approach is usually suited to continuous testing to failure. This is the ideal approach, but is impractical on many types of electrical equipment at this time;
 - 2) Each ageing factor is applied successively in a cyclic manner. In this case, no interactions are possible, but reactions to previous conditionings are possible. Diagnostic factors may be used to determine an end-point; and
 - 3) Each ageing factor is applied individually, as done when one factor is important [see (1) above]. In this case, no interactions will occur.

The difference between ageing factors and diagnostic factors, which are applied for assessing the end of useful life, should be borne in mind (see 7.4).

7.3.2 Acceleration of Functional Tests — Acceleration is obtained by forced ageing. In some cases, transformation rules enabling estimation of the acceleration factor can be deduced when the mechanism of the ageing process is known (for example, that the logarithm of life-time is proportional to the reciprocal absolute temperature if ageing takes place by a first order chemical reaction, or that the life-time is inversely proportional to the frequency for ageing by partial discharges at ac).

In the present state of the art, test acceleration is usually obtained by intensifying or accelerating only one of the several ageing factors applied simultaneously.

For long-life applications, a high acceleration is desired to obtain a relatively short test time, but the correlation between test and reality becomes increasingly uncertain with increasing acceleration.

7.3.3 Verification of Unchanged Ageing Mechanism — One principle of accelerated ageing tests is to keep the intensification of stresses to a minimum, thus reducing the risk of introducing a change of mechanism.

A most useful control consists of testing of several stress levels and observing possible changes in the curvature of the life or property curve as a function of the stress level. For example, if the mechanism of thermal ageing is changed with increase in temperature, this may be recognized by a distinct non-linearity of the plot of the logarithm of the time-to-failure *versus* the reciprocal absolute temperature.

Changes of mechanism may be detected by visual inspection if there is a change in the location of failures with increasing magnitude and frequency of stresses.

Changes of an ageing mechanism may also be recognized by quantitative or qualitative chemical analysis of reaction products, by microscopic analysis, by gas chromatography, by thermogravimetry or by thermal analysis (differential thermal analysis, differential scanning calorimetry, etc).

7.3.4 Application and Intensification of Main Factors of Influence

7.3.4.1 General — A list of some important factors of influence, based on an inventory of stresses in different kinds of equipment, is provided in Appendix C.

An ageing factor may be applied to specimens pre-aged by a different factor.

In addition to their use as ageing factors, humidity, mechanical stress and/or proof voltage may be used as diagnostic factors.

7.3.4.2 Temperature — Oven heating provides the most consistent control and recording of temperature exposure, but may not allow for temperature gradients. Where these are important, internal heating should be provided.

Exposure to low temperature should be applied when low ambient temperature represents the most severe ageing conditions (sometimes with electrical or mechanical ageing).

Temperature levels should be specified as steady-state for definite periods, or cycles between established limits based on service requirements.

7.3.4.3 Electrical stress — A distinction should be made between the following cases:

- a) Working voltage, and
- b) Overvoltages (transients) of different kinds occurring in service.

Electrical ageing is particularly important in connection with mechanisms such as partial discharges, tracking and electrolytic ion transport. Raising the voltage amplitude usually increases partial discharge intensity and action in a strongly non-linear way. In many cases, partial discharge effects can be accelerated in a linear way, up to a limit, by raising the frequency of the applied voltage. When high voltage at increased frequency is applied, care shall be taken to avoid excessive heating of the object due to increased electrical losses.

The accelerated simulation of overvoltages (transients) is possible by increasing the number of applications per unit time while maintaining the level and shape of the service surge voltage. It is assumed that the ageing mechanism will not change.

7.3.4.4 Humidification — Humidity is recognized as one of the main causes of variation in the properties of electrical insulation, both from a chemical and a physical point of view. Where hydrolytic stability is important, acceleration may be accomplished by an appropriate combination of humidity and temperature.

7.3.4.5 Special environments — Acceleration conditions should, in every individual case, be carefully considered because no general knowledge is available about quantitative relations between the rate of ageing and the concentration of chemicals, humidity and other environmental factors. When the equipment operates under peculiar atmospheric conditions or is immersed in a liquid, the test conditions should simulate the service conditions.

7.3.4.6 Mechanical stress — When pressure, vibration, impact or thermal cycling are relevant ageing factors, the functional tests should include exposure to such conditions.

When considering alternating mechanical stresses, acceleration by increased magnitude and frequency is possible, although only limited data have been published about the mechanisms and their changes with the magnitude and frequency of the stresses when evaluating insulation systems.

Unintended mechanical resonances have to be avoided.

7.3.4.7 Alternating thermomechanical stress — Such stresses are mostly caused by the different thermal expansion coefficients of metal and insulation

and the occurrence of temperature differences in the system, for example, temperature gradients through the insulation wall.

Acceleration is possible by increasing temperature differences without exceeding normal maxima or minima, by providing increased heating and cooling capability in the test apparatus.

This method will also increase the frequency of stress application.

7.4 Assessing the State of the Specimens and End-Point Criteria

7.4.1 General—The state of the test specimens is assessed by measuring the changes of one or more service-related properties, or by applying a diagnostic factor. An end-point is defined either in absolute terms (property value or level of diagnostic stress), or in relative terms (change in property value expressed in percent of the initial value).

The following cases should be distinguished:

A — Ageing procedure

A.1 — Continuous

A.2 — Cyclic

B — Evaluation of the state of the specimens

B.1 — Non-destructive measurement of property(ies)

B.1.1 — Continuous monitoring

B.1.2 — Periodic measurements

B.2 — Periodic application of a specified test stress (proof tests)

B.3 — Destructive determination of a property

B.4 — Failure under ageing stress

Method B.1 may be applied in combination with either procedure A.1 or A.2. If the measurements are recorded continuously, or by frequent scanning (B.1.1), the time-to-failure is obtained directly, and if periodic measurements are made (B.1.2), it may be interpolated from a graph of property *versus* time.

In both cases, the time-to-failure is determined for each specimen as a continuous variable, and the rate of change of the property appears from the measurements.

Method B.2 is most frequently applied in connection with procedure A.2. The proof test determines whether the tested property of a specimen

is still within the limit of the proof stress (end-point criterion) or not. If the proof test is applied, for example, at the end of each ageing cycle, the time-to-failure is defined as the mid-point of a cycle, and is thus a discontinuous variable. Since the variation during time of the property is not revealed by the test, the method is not as informative as method B.1.

Method B.3 may be applied to either procedure A.1 or A.2. At each time of measurement, a predetermined number of specimens is examined and then discarded. Since the values of the property at the different measuring times are determined on different specimens, the method is more sensitive to variations between specimens than the above methods. It is not possible to obtain time-to-failure for the individual specimens, but the results indicate the general trend of property *versus* time and an average time-to-failure at each ageing stress. In such a test, special attention should be paid not only to the average change of the characteristic but also to its dispersion.

Method B.4 usually applies to procedure A.1 and yields actual time-to-failure.

7.4.2 End-Point Criteria — In most cases, a voltage proof test will suitably demonstrate significant changes of the insulation quality of the insulation system due to ageing. Generally, a defined voltage should be applied periodically. The kind and level of the test voltage shall be specified and should be chosen to have the smallest ageing effect possible.

The presence of moisture in or on dry type windings permits over-voltages to seek out and discern cracks and porosities in insulation which may result from faulty construction, physical damage, or ageing.

In establishing a voltage proof test level, consideration should be given to using the generally accepted service inspection practices employed by the users of the equipment under study.

For voltage endurance tests the failure of the test specimen usually represents the end-point.

For mechanical endurance tests, mechanical failure may be accepted as an end-point criterion only if positively detectable; otherwise periodic application of a suitable proof test will be necessary.

NOTE — Attention should be given to the fact that some insulation systems which have completely lost their mechanical quality are still able to withstand high electrical stresses but, under high mechanical stresses (for example, short circuit), or when exposed to high humidity, can be destroyed under voltage corresponding to service level, or even lower.

7.5 Functional Test Procedure

7.5.1 General Considerations — The aim of comparative tests, usually with acceleration, is a performance prediction with an accepted confidence level which depends on the representativeness of the test conditions, their reproducibility (including specimen preparation and handling), and on the accuracy of the end-point determination. The more similar the investigated insulation system is to the reference system and the better it is known in advance, the higher will be the confidence of the evaluation. Consequently, the test procedure may differ with respect to complication if different evaluation cases are to yield the same degree of confidence. In the following list, several typical cases are given in decreasing order of confidence, if the testing costs for a given insulation system are kept on the same level in the different cases. At the same time, the arrangement of the list corresponds to an increasing degree of complexity of the test procedure, essentially with respect to the number of ageing conditions, if about the same degree of confidence is aimed at:

- a) Verification that an insulation system, for example, after transfer of manufacture to a new plant, is identical with one which has been earlier evaluated and is service-proven;
- b) Evaluating an insulation system after minor modification (materials, technology) of a known and service-proven system;
- c) Evaluating an insulation system which, after previous evaluation, already has a (preferred) code, for the requirements of a reasonably more severe and/or different code (in such cases, the results of the new and the previous test may be considered in combination; but see last paragraph of 7.5.2);
- d) Evaluating a new insulation system which is basically similar to the reference system; and
- e) Evaluating a new insulation system which essentially differs from the reference system.

Before test methods are confirmed by a Technical Committee for a specific equipment, their validity shall be demonstrated by evaluating service-proven insulation systems.

7.5.2 Specifying Test Procedures — A complete test procedure for the evaluation of a new insulation system [that is, case (d) or (e) of 7.5.1] should be specified.

This procedure should relate to a typical application (in terms of factors of influence, performance and duty) as represented by a preferred code.

Rules should also be given for modifying the levels of the complete test given above in order to qualify the new insulation system for the requirements of a non-preferred code which is not too different from the preferred code.

Simplified procedures for evaluating more or less known insulation systems [that is, the cases (a) to (c) of 7.5.1] should also be specified. Such procedures will normally be derived from the complete test procedure, for example, by reducing the number of ageing conditions. The rules for such partial or supplementary tests should include directions concerning the conditions under which they are applicable.

For a given procedure, previous results obtained with the reference insulation system may, in principle, be compared with new results from the system to be evaluated. It is, however, desirable to evaluate both insulation systems simultaneously in view of the experimental uncertainties normally encountered in practice due to the limited reproducibility of the preparation, exposure and handling of the specimens.

7.5.3 List of Items to be Considered for Each Test — The Technical Committee should verify that each of the following items which are relevant to a particular test have been precisely dealt with in its description of that test:

- a) Whether models may be used;
- b) How models are to be produced;
- c) The number of test specimens;
- d) Whether test specimens are to be conditioned or pre-aged before functional testing;
- e) Which screening tests should be performed;
- f) Types of ageing stresses to be applied;
- g) Levels of ageing stresses (to give acceptable acceleration), with tolerances;
- h) Whether ageing stresses are to be applied continuously or cyclically;
- j) Whether ageing stresses are to be applied singly or simultaneously;
- k) Sequence of tests;
- m) Duration of cycles;
- n) Number of cycles;
- p) Frequency, level and type of diagnostic factors to be applied;

- q) Levels of stresses used as end-point criteria for proof tests or values in tests giving numerical results; and
- r) What statistical treatment of results is appropriate.

7.6 Procedure for Deriving Estimated Performance from Test Results — The derivation of estimated performance from primary test results depends on conditions concerning the codes and also the test procedure:

- a) Whether the test is complete or simplified (*see 7.4.2*),
- b) Whether *P* in the codes is specified as 'Acceptable life' or by ranges, and
- c) Whether the test implies a pass criterion (requirement that a prescribed number of specimens of a group is still alive after the specified ageing procedure) or yields actual time-to-failure.

NOTE 1 — General rules regarding the methodology of evaluating test results for purposes of coding are under consideration.

NOTE 2 — If the new insulation system marginally fails to pass the test, it might, without additional testing, be qualified for a less severe code, but only if the Equipment Technical Committee has included pertinent rules in their specifications for such cases.

7.7 Procedures for Deriving Estimated Performance Without Testing — The practice of evaluating insulation systems on the basis of endurance figures for individual insulating materials is not valid.

The qualification of an insulation system for the requirements of an insulation system code without functional testing should be permitted in the following two cases:

- a) The insulation system is already qualified by a code for a different kind of equipment and this code clearly covers the requirements of the envisaged code with respect to complexity and severity; and
- b) The insulation system has accumulated a satisfactory service record in the envisaged equipment. Appropriate evaluation rules shall be given by the responsible Technical Committee.

7.8 Examples — For the purpose of illustration, hypothetical examples of test and evaluation specifications are given in Appendix A.

The procedures provided in the examples should definitely not be considered as guidelines but only as an illustration of the main principles of this guide. This applies particularly to the design of models, the levels of the factors of influence, the use of diagnostic factors, the methods of evaluating test results, etc. These examples are purposely incomplete and imprecise.

SECTION 4 AGEING MECHANISMS AND DIAGNOSTIC PROCEDURES

8. AGEING MECHANISMS AND THEIR VERIFICATION

8.1 Verification of Service-Related Ageing Mechanisms

8.1.1 Different approaches to this aspect are:

- a) assessment of the insulation system itself,
- b) measurements related to the ageing stresses, and
- c) checks in connection with the evaluation of test results.

8.1.2 Changes of the specimen and degradation products emanating from it are monitored by suitable diagnostic methods. These are selected (*see list in 9*) in the light of knowledge or assumptions regarding the physical and chemical process induced by the ageing factors. Such changes may effect:

- a) the structure of the insulation,
- b) its electrical properties,
- c) its mechanical properties,
- d) its chemical composition and the liberation of constituents and degradation products, and
- e) its visual appearance or optical properties.

It should be ensured that the ageing stresses acting on the test specimen are sufficiently representative of service conditions. This applies to all kinds of ageing factors used during evaluation tests (thermal, electrical, environmental, mechanical). Whenever, they are used alone in sequence or in combination useful information regarding ageing mechanism may be derived from the tests as follows:

- a) Analyzing the stress-time relationships,
- b) Checking the distribution of the times to end-point within a batch of specimens, and
- c) Comparing the failure locations at various stress levels and observing whether they occur under action of ageing stresses or when a diagnostic factor is applied.

8.2 Investigation on the Insulation System Itself

8.2.1 *Physical Investigation* — During ageing, the measurement of some

physical state or property and the comparison of results obtained at various stress levels and at various times may yield pertinent information on the ageing process.

Such properties are mainly electrical or mechanical and concern also the internal structure of test object. For example, structural changes can be detected by a change in elasticity, hardness, etc. Partial discharge intensity may be of value to detect changes in the structure of an insulation system.

When electrical ageing is involved, particularly at increased frequency, it is advisable to determine dielectric loss as a function of frequency at the test temperatures in order to avoid abnormally high dielectric heating during ageing test as in some cases dielectric heating could lead to thermal instability and make the ageing process unrepresentative of actual service. This can occur even at the power frequency, usually at the higher level of temperature. Adjusting the test frequencies or introducing temperature control may therefore be required.

8.2.2 Chemical Investigations — Chemical analysis of test specimens is not so general a technique as physical investigations, but in some cases it can give useful information concerning the ageing process. For example, the rate of increase of acidity and the change in the nature of the products of degradation may be closely related to the ageing process. This applies to insulation systems which include a liquid or gaseous (for example, SF_6) dielectric. In a similar way, monitoring the consumption of anti-oxidants can allow comparisons of ageing at different stress levels to be made. Solubility of certain specimens may give information on the ageing process.

The rates of diffusion among adjacent components of insulation system and between such components and the environment ought to be taken into consideration. An insulating gas may be contaminated by the release of compounds from other components of the insulation system or from its container.

8.2.3 Physico-Chemical Investigations — These investigations could follow any one of the methods given below:

In the analysis of gaseous degradation products during ageing, the most widely used method of investigation is gas chromatography, possibly in combination with mass spectroscopy. Hydrogen, carbon, oxides and light hydrocarbons are to be found among gaseous products of degradation which are formed from organic materials. Except for mechanical stresses, which usually do not generate gases, the degradation products are, in most cases, not dependent upon the kind of stress involved. The particular degradation products encountered are indicative of the actual energy dissipated at the molecular level under the action of the applied stress.

The fact that certain degradation products exist or do not exist can be representative of a change in the ageing process. In particular, as the stress at the molecular level increases, the products of degradation tend to be more unsaturated (for instance, acetylene, propyne, etc). At some stress levels, entirely new unsaturated products can appear, and the ratio of unsaturated products to saturated products may increase at higher stress levels.

Ageing may also be reflected by a change in the degree of crystallinity of a polymer.

Infra-red spectrophotometry may reveal the formation of new structural groups in insulating materials.

Thermal analysis methods, for instance differential thermal analysis (DTA) or differential scanning calorimetry (DSC), reveal changes of physical transformation temperatures which may be indicative of ageing.

Optical microscopy is applied to reveal changes of the microstructure in polymer insulation.

Scanning electron microscopy is applied to reveal surface structure and its changes caused by ageing.

Other changes, for instance degree of polymerization or change of weight, may also be indicative of ageing.

8.3 Measurement Related to the Ageing Factors

8.3.0 The observations contained in Sections 1 to 3 and evaluation of insulation systems of electrical equipment, primarily concern single ageing factors. Additional complications arise with the simultaneous application of more than one factor, even if only one factor is intensified.

8.3.1 Thermal Ageing — When the temperature level is the main ageing factor, the heating method should provide for an appropriate temperature distribution within the specimen (*see 7.3.4.2*).

Temperature gradients influence diffusion and they may be affected by dielectric heating. These effects should be taken into consideration when designing the test and the test specimen may require cooling.

The intended temperature distribution in the test specimen should be verified.

Specimens are commonly aged in an oven where temperature tend to be uniform. Correlation of this ageing temperature with expected operating temperature distribution may be important.

8.3.2 Electrical Ageing — Various measuring methods are available to check the electrical state of a test specimen.

The recording of amplitude and time distributions of partial discharges is a powerful diagnostic tool. Comparison of such distributions at test and service levels of the electrical stress may provide a verification of the validity of the intensification both in level and in frequency. If above a certain voltage level partial discharges occur with amplitudes significantly higher than in actual service, the validity of these test results shall be carefully considered.

Increasing the voltage has different consequences under different conditions. In a small void, the amplitude of the partial discharge pulses and the affected area will not change, but the number of pulses per unit time changes in a stepwise manner. In a gap with constant thickness the pulse size may be not vary greatly up to a certain voltage limit, but the geometrical distribution of pulse sites will change.

The edges of flat, thin void may be more heavily subjected to discharges than the interior. In irregular cavities, different regions are exposed at different voltages. Moreover, the individual discharges may change in character by increasing secondary tangential discharges.

Dielectric losses as function of voltage, the maximum discharge per cycle, the indication of the dielectric loss analyzer and the quadratic rate of apparent charges provide characteristics which permit an overall judgement of partial discharge intensity.

It is known that in some cases low-amplitude partial discharges can have a significant degrading effect compared with the effect of larger discharges, depending on the medium in which they occur.

At present partial discharge measurements still cannot be unequivocally correlated with the phenomenon of transient.

Electrolytic degradation should be related to the temperature and humidity level. Such degradation has been observed even with alternating current.

8.3.3 Environmental Ageing — When an insulation system is designed to be used in a particular environment (gas or liquid) test procedures should take the environment into account. Changes of the environment often produce change in the degradation mechanism, and such changes should be avoided. For example, changing the gaseous environment may affect both the intensity and the chemical degrading mechanism of partial discharges. It should be noted that in many types of equipment, gases or liquids are part of the insulation system.

Care should be taken to prevent products of degradation, including water, from accumulating on or around the test objects in quantities considerably in excess of those that may occur under service conditions.

8.3.4 Mechanical Ageing — In mechanical ageing, when vibration is applied, it should be verified that the stress distribution is sufficiently representative and that resonances do not occur unless explicitly desired.

If transient thermo-mechanical stresses are involved, not only the rate of change of the applied temperature should be considered but also the rate of propagation of the thermal wave within the specimen.

Care should be taken to ensure that thermal or mechanical test acceleration does or does not cause relative motions between components of the test object, as is the case in service.

8.4 Evaluation of Test Results

8.4.1 Stress-Time Relationships — If test results at different stress levels are evaluated to give a life curve, its deviation from the form expected on the basis of a theory for the ageing mechanism, if available, or possibly of previous satisfactory experience, suggests a change of ageing mechanism.

A discerned change of slope at higher stress levels is clearly indicative of a change in the ageing mechanism. When the slope of the curve changes substantially at higher stress levels, the results at these levels should be disregarded in the final evaluation of the insulation system.

8.4.2 Statistical Distributions — It may occur that the distribution of the individual times-to-failure within a batch can be clearly interpreted as belonging to two or more different distributions. In such cases, suspect specimens should be examined for possible defects. If physical differences among the specimens are not revealed, the whole batch shall be considered together. This may affect the decision concerning the appropriate type of statistical analysis to be employed.

The conditions for deletion of test values is the identification of abnormalities in the specimens, that is, the purpose of the evaluation is to determine the characteristics of good insulation.

8.4.3 Location of Failure — Inspection of the specimens after the test may provide pertinent information. If the end of life consists in an observable weakening or rupture of the test specimen, its location may be indicative of a change in the ageing process conclusions can sometimes be drawn concerning the dielectric strength of specimens if the location of the punctures is known with respect to the geometrical distribution of the ageing stresses.

Failure may occur either under the actual ageing stress or during application of a diagnostic stress. This inspection for defects applies principally when a failure occurs under a mechanical or electrical stress.

Example — If at higher levels of voltage stress, for voltage endurance tests, most failure occur at the edge of an electrode and the distribution of puncture locations at lower stresses is random, they may indicate a change in ageing mechanism. However, it should not necessarily be inferred that either type of failure is characteristic of service failures.

9. DIAGNOSTIC TECHNIQUES

9.1 Classification — All methods for the assessment of the state of specimens and for the detection of ageing mechanisms should be low ageing effect compared with the ageing in the test. Diagnostic procedures for monitoring of properties of insulation systems during service or ageing or ageing tests may be categorized in the following way:

- a) *Non-destructive Tests* — In these tests stress has a negligible effect on ageing;
- b) *Possibly Destructive Tests* — These tests are those with low influence on ageing if used as short-time tests for periodic application. If any stress of possibly destructive character is used for continued monitoring of ageing it has to be demonstrated that its influence on ageing is negligible compared with the intended ageing by other factor.
- c) *Destructive Tests* — These tests are used as end-point criteria or as means of determining the trend of a materials characteristic, such as electric strength or mechanical strength, with time of ageing. If destructive diagnostic procedures are to be used and the test results are to be statistically evaluated, a sufficient number of specimens should be tested to destruction.

A list of some possible diagnostic procedures is given in Table 1.

TABLE 1 DIAGNOSTIC PROCEDURES

(Caluse 3.1)

SL No.	TYPE OF TEST	REFERENCE	NATURE OF TEST		
			Non- destr- uctive	Possibly destruc- tive	Destr- uctive
1. Electrical					
a)	Insulation resistance	IS : 2259-1963*	×		
b)	Dielectric polarization or depolarization current versus time	—	×		
c)	Dielectric constant	IS : 4486-1967†	×		
d)	Dielectric losses and their variation with voltage frequency	IS : 4486-1967†	×		
e)	Surface resistivity	IS : 3396-1979‡	×		
f)	Partial discharges — Inception and extinction voltage; amplitude; number; quadratic rate	IS : 6209-1982§	×		
g)	Dielectric properties as a function of temperature [items (a) to (f)]	—	×		
h)	Tracking resistance	IS : 2824-1975		×	×
j)	Service voltage proof tests:				
i)	Direct voltage			×	
ii)	Alternating voltage			×	
iii)	Impulse voltage			×	
iv)	Surge voltage			×	

*Methods for test for determination of insulation resistance of solid insulating materials.

†Recommended methods for the determination of the permittivity and dielectric dissipation factor of electrical insulating materials at power, audio and radio frequencies including metre wavelengths.

‡Methods of test for volume and surface resistivity of electrical insulating materials (*first revision*).

§Methods for partial discharge measurements.

||Method for determining the comparative tracking index of solid insulating material under moist conditions (*first revision*).

(Continued)

TABLE 1 DIAGNOSTIC PROCEDURES — *Contd*

SI No.	TYPE OF TEST	REFERENCE	NATURE OF TEST		
			Non- destr- uctive	Possibly destruc- tive	Destr- uctive
	k) Overvoltage proof tests (independent of type of service voltage)	—			
	i) Direct voltage			×	
	ii) Very low frequency (0.1 Hz)			×	
	iii) Alternative voltage (50 Hz/60 Hz and higher test frequencies)			×	
	iv) Half-wave test			×	
	v) Impulse test			×	
	vi) High-frequency test with damped oscilla- tions			×	
	m) Overvoltage test (increased or maintained until break- down)				×
2.	Physical—Mechanical	IS : 9000*			
	a) Hardness		×		
	b) Elasticity		×		
	c) Stiffness		×		
	d) Tension			×	×
	e) Bending			×	×
	f) Torsion			×	×
	g) Elongation			×	×
	h) Compression			×	×
	j) Vibration			×	×
	k) Impact			×	×
	m) Resonance frequency and damping		×		×
	n) Bond strength				×

*Basic environmental testing procedures for electronic and electrical items.

(*Continued*).

TABLE 1 DIAGNOSTIC PROCEDURES — *Contd*

Sl No.	TYPE OF TEST	REFERENCE	NATURE OF TEST		
			Non-destructive	Possibly destructive	Destructive
	p) Determination of integral stresses				×
	q) Weight loss		×		
3.	Chemical				
	a) Analysis of products of degradation				
	i) Gas chromatography				
	ii) Mass spectrometry		×		
	b) Analysis of components of the system		×		
	i) Infra-red spectrophotometry		×		
	ii) X-ray diffraction		×		
	c) Ambient influence (humidity, dust, etc)	IS : 9000*		×	
	d) Differential thermal analysis				
4.	Visual inspection				
	a) Evaluation of colour and colour changes		×		
	b) Surface condition (smooth or rough)		×		
	c) Deposit of oil, humidity or other contaminations		×		
	d) Location and appearance of failures		×		
	e) Dimensions, size		×		
	f) Dissection			×	
	g) Macroscopic inspection			×	
	h) Microscopic inspection			×	

*Basic environmental testing procedures for electronic and electrical items.

APPENDIX A

(Clauses 5.1, 5.10 and 7.8)

HYPOTHETICAL EXAMPLES OF SPECIFICATIONS FOR EVALUATING AND IDENTIFYING PARTICULAR INSULATION SYSTEMS

A-0. GENERAL

A-0.1 Examples of specifications for the evaluation and identification of insulation systems for two types of equipment are given here. It cannot be emphasized strongly enough that these examples shall not be understood to be guidelines nor do they necessarily represent the actual state of the art.

A-0.2 The examples have been drafted to illustrate two different considerations. One example deals with the insulation in a type of equipment produced in large number, whereas the other one concerns insulation for individually designed equipment. The first example is intended to demonstrate how existing Indian Standard could be transformed to follow this, if an Equipment Technical Committee chooses such an approach. The second example, on the other hand, is intended to demonstrate the possibilities of this guide.

NOTE — This example is based on IS : 6616-1982*. Only two ageing factors are taken into account.

This specification is assumed to be issued as IS : 000.

A-1. EXAMPLE 1

INSULATION SYSTEMS FOR BALLASTS FOR HIGH-PRESSURE MERCURY VAPOUR LAMPS

1. SCOPE

1.1 This standard applies to the coding and functional testing of insulation systems for inductive type ballasts for use on an ac supply at 50 Hz or 60 Hz associated with high-pressure mercury vapour lamps having rated wattages, dimensions and characteristics as specified in IS : 9900 (Part 1)-1981†.

*Specification for ballasts for high pressure mercury vapour lamps (*first revision*).

†Specification for high pressure mercury vapour lamps : Part 1 Requirements and test.

2. INSULATION SYSTEM CODES

2.1 The following coding elements are considered to be relevant for the insulation system codes:

T = rated maximum insulation temperature (°C),

E = nominal voltage (V), and

P = intended performance: duration of continuous service at the rated maximum temperature (years).

The format of the insulation system code is:

[IS : 000] INS $TE-P$

The symbols T , E and P represent digits according to the following table:

	T °C	E V	P years
1	NA	NA	NA
2	NA	NA	NA
3	90	< 250	NA
4	105	250 to 500	NA
5	120	NA	10
6	NA	NA	NA
7	NA	NA	NA
8	NA	NA	NA
9	NA	NA	NA

The use of code digits marked NA (non-applicable) is not authorized.

NOTE — Changing NA to new rating can be performed only by concerned Technical Committee.

Each digit in each column may be combined with whatever digit of another column to yield a complete code. There are six possible combinations.

For example, a ballast intended for 10 years of operation at 100°C and a nominal voltage of 380 V 50 Hz requires an insulation system demonstrated to fulfil the requirements of either one of the codes [IS : 000] INS 44-5 IS : 000 INS 54-5. The following tabulated format is recommended (for example, for the digit sequence 44-5):

Identification	T	E	P
[IS : 000] INS	4	4	5

3. FUNCTIONAL TEST PROCEDURE

NOTE — Comparative function testing of new and service proven insulation system is strongly recommended in this guide.

This principle is not explicitly applied in IS : 6616-1982*. However, it is implicit in the constant 4 500 in the formula in 3.6.

3.1 Ballasts Specification

Rated maximum temperature of the winding.....	90°C, 105°C or 120°C
Nominal voltage	24 V up to 500 V
Frequency	50 Hz or 60 Hz
Rated wattage	50 W up to 2 000 W
Intended performance.....	10 years of continuous service at the rated maximum temperature

3.2 Test Specimens — The test specimens should be from the actual production and be complete ballast as used in operation.

3.3 Ageing Factors to be Applied on the Specimens — Simultaneous application of voltage and temperature.

3.4 Number of Specimens — Seven specimens should be tested.

3.5 Testing Conditions — Testing equipment should be designed in such a way that both stresses (voltage and temperature) can be applied simultaneously.

According to practical experience, uniform and stable temperature can be achieved in two ways either:

- a) by an oven, which is not provided with a good thermal insulation; or
- b) by very good thermal insulation of the ballasts so that they themselves provide (most of) the heat needed for the test.

The description given in following paragraphs refers to the 'oven method'. When 'self-heating' is used, the current through the ballast should be kept constant instead by the thermostats.

The ballast shall function electrically in a manner similar to that in normal use. In the case when capacitors or other components which

*Specification for ballasts for high pressure mercury vapour lamps (*first revision*).

should not be subjected do the test are present, they shall be connected outside the oven. Other components which do not influence the operating conditions of the windings may be removed.

In general, the ballast will be tested with the appropriate lamps, but for certain inductive type ballasts, these lamps may be replaced by equivalent resistances adjusted to obtain the mean value of current through the ballast. These lamps or resistances shall be kept outside the oven. The ballast shall be earthed.

The batch of seven ballasts is placed in the oven, observing the minimum prescribed spacing limits, and the rated voltage is applied.

The oven thermostats are then varied in such way that the temperature of the hottest winding in the ballast is equal to the test temperature, controlled by the 'increase in resistance' method. This temperature is checked daily and maintained within $\pm 2^{\circ}\text{C}$.

3.6 Acceleration of the Test — Only the thermal ageing factor will be accelerated. The test temperature will be chosen on the basis of the following formula:

$$\log L = \log L_0 + 4\,500 \left(\frac{1}{T} - \frac{1}{T_w} \right)$$

where

L = test duration in days,

L_0 = estimated performance (in days) at the maximum rated operating temperature,

T = test temperature in kelvins, and

T_w = maximum rated operating temperature in kelvins.

The constant 4 500 has been established empirically. The test temperature should be selected in such a way that the test duration be 30 to 50 days for an estimated performance L_0 of 3 652 days (10 years).

3.7 End-Point Criteria — Not less than three times per week (after the first week), the ballasts under test will be submitted to proof tests at the ageing temperature. The following points will be checked:

- a) The ballast shall start and operate the lamp within the prescribed current limits;
- b) The magnetic losses measured under rated current shall not increase by more than 10 percent compared to the initial values measured at the same temperature;

- c) The insulation resistance of the windings measured under 500 V dc shall not be less than 1 M Ω ; and
- d) The ballast shall withstand a proof test of twice the nominal voltage during 1 minute.

The end-point is reached when any of the four points (a), (b), (c) or (d) is not satisfied.

3.8 Determination of Time-to-Failure — The test duration (logarithmic average of time-to-failure) in the formula in 3.6 is the number of days of satisfactory behaviour of the ballasts.

In practice, when an end-point criterion is reached, L will be equal to the duration of ageing until the last proof test passed by the specimen.

3.9 Presentation of Test Results — The test report shall include the following information:

- a) Description of test specimens:
 - 1) Type of ballast,
 - 2) Nominal voltage,
 - 3) Nominal wattage, and
 - 4) Maximum rated operating temperature.
- b) Test stresses applied:
 - 1) Temperature and method of heating,
 - 2) Voltage level and frequency, and
 - 3) Proof tests used for end-point.
- c) Test results — individual time-to-failure and their logarithmic average.

3.10 Evaluation of Test Results — The estimated performance of the tested insulation system is L_0 as derived from the test duration L by means of formula in 3.6. L_0 shall be 3 652 days or more. If this condition is fulfilled, the insulation system is given a code with T -rating corresponding to T_w of the formula, and an E -rating corresponding to the ageing voltage.

A-2. EXAMPLE 2

NOTE — This example refers to insulations covered by IS : 4722-1968*. It is assumed that a hypothetical revision, to be issued in 1990 will contain the same categorization of windings, although this may be diversified for practical reasons.

*Specification for rotating electrical machines.

In order to simplify the example and to demonstrate the versatility of this guide, the influence of environmental conditions is not taken into account.

The insulation system codes are intended to cover the whole field defined in the scope, whereas the functional test specification applies to chosen special cases only.

The statement in the last paragraph of the introduction and in 7.8 concerning the intended incomplete and unrealistic nature of the examples applies particularly to this example.

INSULATION SYSTEMS FOR HIGH VOLTAGE AC STATOR WINDINGS OF ROTATING ELECTRICAL MACHINES

1. SCOPE

1.1 This specification applies to the coding and functional testing of insulation systems for high-voltage ac stator windings (1 kV or more) of machines having an output of 5 MW (or MVA) or more, having a core length of 1 m or more and operating in an uncontaminated atmosphere, irrespective of the method of cooling.

2. INSULATION SYSTEM CODES

2.1 Format and List of Codes

The following coding elements are considered to be relevant for the insulation system codes:

T = maximum insulation temperature (°C),

E = nominal voltage (kV);

M_1 = transient mechanical stress;

M_2 = permanent vibration induced in the machine or transmitted to it, thermo-mechanical stress;

P = intended performance : acceptable life, or actual time of operation (thousands of hours); and

D = number of operations (changes from rest to load) (per year).

NOTE — An intended performance figure is a statement of typical insulation behaviour without any implication concerning a possible commercial life guarantee.

The format of the insulation system code is:

IS : 4722-1968 : INS $TE0$ ($M_1 M_2$) — PD

IS : 11182 (Part 1) - 1984

The symbols T , E , M_1 , M_2 , P , D represent digits 1 to 9 according to the following Table. In addition, the digit 0 may be used to indicate that a code element refers to a stress level considered not to be significant. The symbol \times may be used to indicate a significant stress level which cannot yet be specified.

	T °C	E kV	M_1	M_2	P 10 ³ hours	D per year
1	NA	NA	NA	NA	Acceptable life	NA
2	105	< 3	Small	NA	50	< 10
3	NA	< 7	NA	Low	NA	NA
4	130	NA	Medium	NA	100	< 100
5	155	NA	NA	NA	NA	NA
6	180	< 17	NA	NA	250	< 1 000
7	NA	> 17	High	High	> 250	NA
8	NA	NA	NA	NA	NA	< 10 000
9	NA	NA	NA	NA	NA	> 10 000

NOTE 1 — When the symbol $>$ is used, a precise value should be agreed upon.

NOTE 2 — In the preparation of this example, it is recognized that the mechanical stresses are probably one of the most important factors acting upon the insulation in large rotating machines. Even through this appendix is only an example, it was felt that quantitative numbers should not be inserted because of future inference that the selected levels of influences were necessarily significant. Contrary to other factors of influence, not enough is yet universally understood and agreed to by experts in the field of rotating machines about the effects of mechanical forces. Hence, the expressions low, medium and high are used. It is the desire that experts in Technical Committee will vigorously pursue a better understanding of the mechanical forces so that after Technical Committee accepts this guide, they will be able to write their own appropriate rules, which will include quantitative numbers for the mechanical factors.

The use of code digits marked NA (non-applicable) is not authorized.

NOTE — Changing NA to new ratings can only be performed by concerned Technical Committee in a later revision of IS : 4722-1968.

Each digit in each column may be combined with digits of other columns to yield a complete code. There are 2 400 possible combinations in this Table.

2.2 Codes and Preferred Codes for Particular Types of Stator Windings — All the possible codes are certainly not relevant to each particular winding

type. In order to restrict number of codes to be considered for the stator windings of the most important machine types, codes representing typical service conditions are listed in the second column of the following table.

In the third column, preferred codes are listed to which the main functional test procedures for evaluating the capabilities of insulation systems will be related in later sections of this standard.

TYPE OF MACHINE	CODE OF ELEMENTS REPRESENTING TYPICAL SERVICE CONDITIONS							PREFERRED CODES		
	<i>T</i>	<i>E</i>	<i>A</i>	<i>M₁</i>	<i>M₂</i>	<i>P</i>	<i>D</i>	(Identification) INS <i>TEA</i> (<i>M₁ M₂</i>) — <i>P D</i>		
Base-load turbo- generators	4	6	0	x	x	6	2	IS: ... INS	470 (xx) — 62	
	5	7						IS: ... INS	570 (xx) — 62	
Peaking turbo- generators	4	6	0	x	7	1	6	IS: ... INS	460 (x7) — 26	
	5					2	8	IS: ... INS	560 (x7) — 26	
	6							IS: ... INS	560 (x7) — 16	
Base-load hydro- generators and 5 synchronous compensators (bulb generators not included)	4	3	0	2	0	6	2	IS: ... INS	460 (20) — 64	
	5	6				7	4	IS: ... INS	560 (20) — 64	
		7								
Pump hydro- generators	4	6	0	7	7	1	6	IS: ... INS	460 (77) — 16	
	5							IS: ... INS	560 (77) — 16	
Synchronous motors	4	2	0	4	x	2	6	IS: ... INS	420 (4x) — 28	
	5	3					8	IS: ... INS	430 (4x) — 28	
		6						IS: ... INS	460 (4x) — 28	
								IS: ... INS	530 (4x) — 28	
Asynchronous motors	4	2	0	2	3	2	6	IS: ... INS	420 (77) — 29	
	5	3		4	7	6	9	IS: ... INS	430 (77) — 29	
		6		7				IS: ... INS	460 (77) — 29	
								IS: ... INS	520 (77) — 29	
								IS: ... INS	530 (77) — 29	
								IS: ... INS	560 (77) — 29	

NOTE — In spite of the tremendous number of possible codes, the actual number of preferred codes, that is of main test procedures, to be considered for one type of machine is from two to six.

2.3 Tabulated Format — The following format is recommended, for example for the digit sequence 420 (77) — 29:

Identification	<i>T</i>	<i>E</i>	<i>A</i>	<i>M</i> ₁	<i>M</i> ₂	<i>P</i>	<i>D</i>
IS : 4722-1968	4	2	0	7	7	2	9

2.4 Example : Choosing a Code to Represent an Actual Service Requirement — Large direct water-cooled base-load turbo-generator stator winding for 25 kV, maximum insulation temperature 90°C, intended performance 20 years:

IS : 4722-1968 1 INS 470 (XX) — 62

NOTE — In this hypothetical example, the level 2 for *T* cannot be used in view of the table in 2.2.

3. FUNCTIONAL TEST PROCEDURE

NOTE — This clause contains one single main test procedure to qualify a new insulation system for one preferred code for a certain type of machine, and a supplementary test procedure for an ordinary code for the same machine type, for an insulation system already possessing this preferred code.

3.1 Main Test Procedure

3.1.1 Type of Machine — Base-Load Hydro-Generator with Air-cooled Stator Windings.

Maximum temperature.....	155°C
Nominal voltage.....	7 kV to 17 kV
Frequency.....	16 Hz to 60 Hz
Ambient.....	normal air
Intended performance.....	25 years of actual operation
Duty.....	continuous with less than 10 starts per year

This specification corresponds to the preferred code:

IS : 4722-1968 : 1 INS 360 (20) — 64

3.1.2 Basic Condition for the Main Test Procedure — The evaluation of the new insulation system is performed by a comparative test to which an available service-proven insulation system is also submitted.

This reference insulation system has already a code identical to the preferred code stated in 3.1.1 or, alternatively, a code with a lower thermal rating.

3.1.3 Test Programme

3.1.3.1 Ageing factors — Thermal endurance temperature at three levels related to the maximum temperature of the code (without voltage).

3.1.3.2 Voltage endurance — Voltage at three levels, at one temperature.

3.1.3.3 Diagnostic factors (for the thermal endurance test only):

- a) Mechanical vibration,
- b) Humidification, and
- c) Proof voltage.

3.1.4 Thermal Endurance

3.1.4.1 Test specimens — Specimens may be actual bars or coils or test bars.

The insulation thickness, both for the turb and the ground insulation, shall be that of a normal winding for 17 kV. Strand insulation, if present, shall be of the same kind and thickness as in actual windings. Reasonable allowance in the copper cross-section is permitted. The specimens are to be processed in the same way as in actual production and individually submitted, for screening purposes, to the same non-destructive quality control tests (for example, proof voltage, $\tan \delta$, chemical composition) as the actual production.

The specimens may be straight bars with active parts not shorter than 0.3 m and ends of such a length that voltage proof tests can be performed without a risk of flashover. Adequate corona protection shall be applied for the proof tests.

The specimens can be mounted either in a multi-slot simulated core, or tightened up, for the length of the active part, between rigid (not less than 3 mm thick) steel plates with adequate clamping devices in both transversal directions.

Nine specimens shall be tested at each temperature (assuming a log-normal distribution).

3.1.4.2 Testing conditions — If the reference insulation system has the thermal rating 5, both insulation systems shall be aged at 180°C, 200°C and 220°C.

If the reference insulation system has the thermal rating 4, it shall be aged at 155°C, 180°C and 200°C and the new insulation system at 180°C, 200°C and 220°C.

The ageing shall be performed in cycles. For considerations concerning the duration of the cycles [see IS : 8504 (Part 1)-1977*].

For the thermal ageing, ovens are suitably used. The temperature variation and fluctuation shall not exceed $\pm 3^{\circ}\text{C}$.

After each ageing cycle, each specimen is allowed to cool below 40°C , tightened up in the clamping device (if used) and vibrated for 1 hour perpendicular to the slot at 50 Hz or 60 Hz with an amplitude of 0.25 mm peak to peak. After humidification 40°C , 95 percent RH during 24 hours, proof test with 26 kV ac for 1 minute. If the specimen passes the proof test, it shall be tightened up again before insertion into the oven.

The test is continued until the failure of the fifth specimen of the group. The time-to-failure is the duration of the ageing cycles until the time when failure was ascertained, minus one half-cycle.

3.1.5 Voltage Endurance

3.1.5.1 Test specimens — The same type of specimen as for thermal endurance shall be used. Corona protection shall be able to withstand the higher stress value and be renewed when necessary.

The length of the test electrode shall not be less than 0.3 m and consist of a length of conductive paint or equivalent. If necessary, a rigid simulated core is clamped on to the specimen.

In order to stop the test after the sixth specimen fails (assuming Weibull distribution), ten test specimens for each ageing voltage shall be tested.

3.1.5.2 Testing conditions — With 50 Hz or 60 Hz voltage the ageing shall be performed at 25 kV, 35 kV and 45 kV. The specimen temperature shall be maintained at $155 \pm 5^{\circ}\text{C}$.

Owing to uncontrolled heating mechanisms, the insulation temperature should be monitored.

Acceleration of the ageing by increasing the frequency of the voltage is permitted, provided adequate measures are taken for keeping the specimen temperature within the range specified, and it is demonstrated that the mechanism of ageing is the same. Ageing shall in this case be performed at 25 kV for one group of specimens and the correspondence with service frequency ageing at this voltage checked (that is approximate inverse proportionality between the time-to-failure and the frequencies). After this control, a lower hf ageing voltage can be applied, for example, 20 kV,

*Guide for the determination of thermal endurance properties of electrical insulating materials: Part 1 Temperature indices and thermal endurance profiles.

in order to obtain equivalent time-to-failure in the range 10 000 h to 100 000 h in a reasonable test time.

The time-to-failure of each specimen is the actual time to breakdown. The test is continued until the sixth specimen of a group breaks down.

3.1.6 Presentation of Test Results—The test report shall contain the following information:

- a) *Description of test specimens* — This section will contain all pertinent information on the specimens and their identification;
- b) *Test equipment*;
- c) *Test stresses applied*:
 - 1) temperature and methods of heating and temperature control,
 - 2) voltage levels and frequencies, and
 - 3) proof tests used for end-point.
- d) *Test results*:
 - 1) thermal endurance — individual time-to-failure at each temperature, and
 - 2) voltage endurance — individual time-to-failure at each voltage (and/or frequency).

3.1.7 Evaluation of Test Results — The evaluation is based on a comparison between the reference and the new insulation system, respectively, and comprises both the thermal endurance and the voltage endurance results. It is stated in terms of estimated performance (in thousands of hours).

3.1.7.1 First step — thermal endurance — The median time-to-failure at each ageing temperature for both insulation systems are plotted in a log time-reciprocal absolute temperature diagram.

If, for either insulation system, the median time-to-failure at the highest ageing temperature is lower than 100 hours, the test shall be supplemented by ageing at a lower temperature.

If the three points for either insulation system are not reasonably aligned, the test shall be supplemented by ageing at one or more appropriate temperatures.

When a satisfactory life plot is obtained, an extrapolation is made to the temperature of the code rating for the new and the reference insulation system, respectively.

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If this extrapolated time is the same or higher for the new insulation system, the first step is satisfied. Otherwise, the new insulation system cannot be qualified for the envisaged preferred code.

3.1.7.2 Second step — voltage endurance — The six time-to-failure of each ageing group are plotted on Weibull co-ordinate paper, and the median value is interpolated. The median values for both systems are plotted in a voltage or log voltage *versus* log time-diagram.

If increased frequency is applied, the actual time-to-failure are converted into equivalent line-frequency values in inverse ratio of the frequencies.

If the shortest median value is less than 100 hours or if the plot is not reasonably linear, additional tests shall be performed at new stress levels.

When a satisfactory life plot is obtained, an extrapolation is made to the voltage of the code rating (the same for both insulation systems). If this extrapolated time is the same or higher for the new insulation system, the second step is satisfied. Otherwise, the new insulation system cannot be qualified for the preferred code.

3.1.7.3 Coding the new insulation system — If the outcomes of the first and second step are both successful, the new insulation system is assigned an estimated performance of 250 000 hours, and it is qualified for the preferred code:

IS : 4722-1968 : 1 INS 560 (20) — 64

NOTE — During the transition from the present methods for insulation characterizations to equipment standards based on this guide, the coding without complete functional testing, of insulation systems which have already acquired a sufficient service record is of particular importance. This is especially the case for identifying the reference insulation systems.

It could, for example, be specified that insulation systems with a satisfactory service record of at least 50 percent of the intended performance, could be assigned a code, and if the service record is at least 25 percent of the intended performance a tentative code be assigned, at factor of influence rating representing the actual service condition.

3.2 Supplementary Test Procedure — provided an insulation system previously been demonstrated to comply with the requirements of the preferred INS : 4722 1968 : 1 INS 560 (20) — 64, and it is to be qualified for the ordinary code INS : 4722-1968 : 1 INS 570 (20) — 64, that is for a higher voltage rating (for example, 25 kV), a supplementary functional test only is required.

This test will be a voltage endurance test performed on new specimens having a wall thickness corresponding to the new 25 kV design but other-

wise like those specified in 3.1.5.1. Two voltage levels only have to be applied. They shall be chosen in such a way as to obtain median time-to-failure values of the order of some hundreds to some thousands of hours, respectively (line frequency values), or, better, more than 10 000 hours (using increased frequency). The test procedure will be identical to that described in 3.1.5.2, and the results are evaluated and plotted as described in 3.1.7.2.

If the plots from this test and from the main test, are reasonably parallel, the new plot is extrapolated to the voltage rating of the envisaged code. If the corresponding time is equal to, or higher than, 250 000 hours, the insulation system is qualified for the code.

IS : 4722-1968 : 1 INS 570 (20) — 64

APPENDIX B

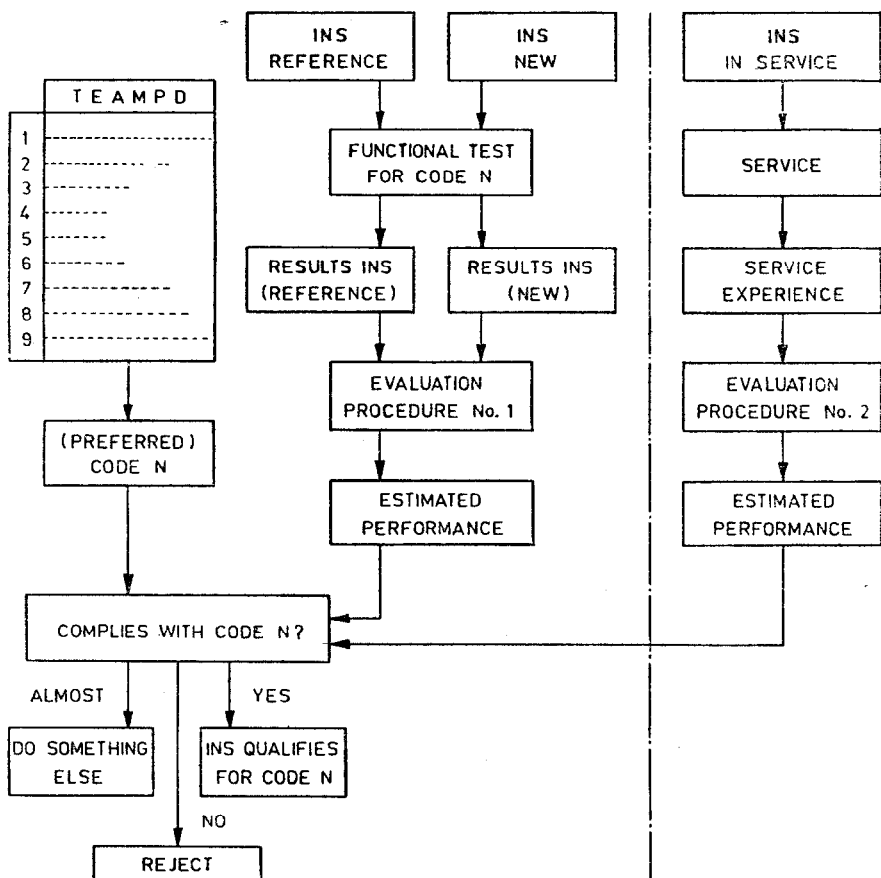
(Clause 5.11)

CODING OF INSULATION SYSTEMS

On the evidence of:

1) functional tests:

2) service:



APPENDIX C

(Clause 7.3.4.1)

LIST OF SOME IMPORTANT FACTORS OF INFLUENCE
AND DUTY RELEVANT TO INSULATION IN ELECTRICAL
EQUIPMENT*Thermal:*

Maximum temperature (<i>see</i> Note 2)	Insulating liquids
Low ambient temperature (<i>see</i> Note 3)	Water (<i>see also</i> Humidity)
High ambient temperature	Semiconductive dust
Temperature gradient	Dust and sand
Rate of temperature change	Fungi
(thermal shock)	Rodents

Electrical:

Working voltage	Humidity
Over voltage (transients)	Nuclear radiation
Frequency	Steam exposure

Partial discharges (*see* Note 4)

Tracking

Flashover

Creeping

Environmental:

Air
Oxygen
Hydrogen
Nitrogen
Inert gases
Sulphur hexafluoride
Different corrosive
atmospheres
(specify which)

Including
effects of
pressure

Mechanical:

Vibration, electrodynamic
Impact, electrodynamic
Vibration, mechanical impact
(*see* Note 5)

Mechanical bending

Pressure

Tension

Repeated compression

Torsion

Duty:

Continuous

Short-time

Intermittent

Intermittent with starting
and electrical braking

Storage and transportation

(*see* Note 6)

Vacuum

Lubricants

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NOTE 1 — The possibility of using uniform symbols for the different variants of the factors T , E , etc., is under consideration.

NOTE 2 — 'Maximum' refers to the hottest part of the insulation system of a particular type of equipment.

NOTE 3 — 'Low ambient' is meant for temperatures below 0°C .

NOTE 4 — Includes partial discharges inside insulation and along outside surfaces.

NOTE 5 — Takes also account of stresses occurring during transportation.

NOTE 6 — Indicates kind and length of storage, if unusual, for example 'very humid', 'very hot', and '12 months'.